

## The development of commercially viable ADR services: introduction of a small-satellite grappling interface

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### ABSTRACT

OneWeb has begun the deployment of its global internet system – one that will bridge the digital divide and bring internet connectivity to underserved communities throughout the world. The backbone of its network is a constellation of nearly 600 low Earth orbit (LEO) satellites that service user terminals designed for a variety of communication use cases.

From its inception, OneWeb has committed itself to the highest standards of responsible design and operational practices and believes that all stakeholders need to take responsibility for the long-term sustainability of space. To assure safe space operations in the presence of collisional hazards, we need to adopt a more comprehensive approach to Space Environment Management (SEM). In addition to improving Space Situational Awareness (SSA), collision avoidance capabilities, and debris mitigation standards, it is critical that the global space community also develop real possibilities for environmental remediation.

There are still some technical challenges to solve before Active Debris Removal (ADR) services become a reality, but the more formidable challenge in developing a commercially viable ADR services industry is likely to be cost. It remains to be seen whether mission architectures and business models can be crafted to support price points that are attractive to commercial operators, or whether ADR is destined to be a service only governments can afford.

As part of its commitment to space sustainability and environmental stewardship, OneWeb is including a grappling fixture on every one of its satellites to facilitate capture in the event that retrieval should become necessary. In addition, OneWeb has worked with Altius Space Machines over the last three years to develop an advanced grappling fixture that accommodates a number of grappling techniques. Furthermore, over the last three years, OneWeb has worked with Altius Space Machines on advanced grappling techniques in the hopes of standardizing a versatile capture interface for on-orbit servicing, thereby lowering the projected cost of ADR and other services for everyone.

The result is Altius' DogTag™ universal grappling fixture, a low-cost, light-weight, universal interface for small satellites. The primary capture mechanism is magnetic, but it is also designed to support mechanical, adhesive, and penetrating capture techniques as well. Altius was recently awarded a contract for almost 600 fixtures by OneWeb Satellites and will begin delivery of flight hardware in December 2019.

## 1 INTRODUCTION

Earlier this year, OneWeb began the deployment of its global internet system to fulfill its mission to bridge the digital divide and bring internet connectivity to underserved communities throughout the world. The backbone of the network is a constellation of nearly 600 low Earth orbit (LEO) satellites that service user terminals designed for a variety of communications use cases. The first six of these satellites were launched in February 2019, and after passing initial checks, they were raised to their operational altitude of 1,200 km and began system integration testing. OneWeb is pleased to report that all systems are nominal across the fleet.

Commercial service will be offered to regions above 60° latitude starting in 2020, and global service will be available in 2021. OneWeb's initial deployment of 12 orbital planes with 49 satellites each are inclined at 87.9° and are evenly spaced in right ascension of the ascending node. This provides the coverage pattern shown in Fig. 1. OneWeb's constellation architecture is scalable and can accommodate more satellites to increase capacity as customer demand warrants.

OneWeb is not alone, however, in having a bold vision for using satellites to offer services on a global scale. New technologies and rapidly declining costs of space access are providing unprecedented opportunities for satellite-based services in global communications, remote sensing, imaging, and other applications that promise to boost economic development, education, healthcare, location-based services, our understanding of environmental processes, and more.



Fig. 1: Global coverage pattern of OneWeb's initial constellation.

Such opportunities have led to a rapid acceleration of commercial space activity that has challenged regulatory frameworks and industry practices, raising questions about the current states of Space Situational Awareness (SSA) capabilities, Space Traffic Management (STM) practices, and debris mitigation guidelines [1-4]. With over 8,400 metric tons of mass in orbit today [5], a history of more than 240 on-orbit fragmentations, and proposals to launch upwards of 50,000 new satellites in the coming years, the global community must broaden its discussions to include a more comprehensive framework for assuring safe space operations in the presence of collisional hazards.

Such a framework has been proposed by Maclay and McKnight [6] and is illustrated in Fig. 2. It posits Space Operations Assurance (SOA) as the goal and suggests that alongside our STM efforts to avoid collisions in our current environment, we must also take a more active role in managing the space environment itself. Thus, Space Environment Management (SEM), which comprises both debris mitigation (limiting the creation of new debris) and environmental remediation (Active Debris Removal, or ADR), complements STM as a second building block to ensure SOA, all of which is supported by a solid foundation of SSA information.

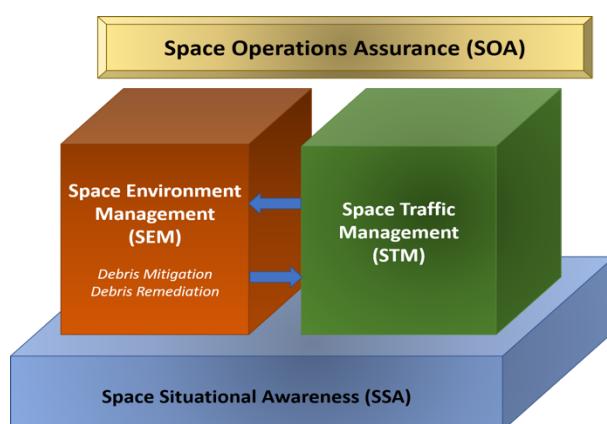


Fig. 2: A comprehensive approach to SOA includes remediation as a critical element of SEM.

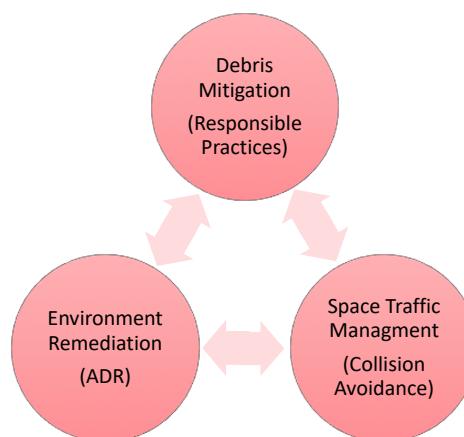


Fig. 3: The challenges faced in each component of SOA is dependent on how effective we are with the other two.

Undoubtedly, a failure to address any one of the areas identified in Fig. 3 increases the need for – or complicates – the other two. For example, failing to remove satellites and rocket bodies from orbit under their own power complicates STM and increases the need for ADR. And while derelict orbital objects present an operational burden to on-going missions in the form of conjunction monitoring and avoidance, a far more dangerous prospect is that they become sources of additional untrackable debris through collisions or explosions.

## 2 CHALLENGES AND OPPORTUNITIES ASSOCIATED WITH REMEDIATION

### 2.1 OneWeb's Commitments to Environmental Stewardship

From its inception, OneWeb has committed itself to the highest standards of responsible design and operational practices. OneWeb believes that space is a shared, natural resource and that all stakeholders must work together to adopt sustainable practices that preserve the orbital environment for generations to come. In keeping with this philosophy, OneWeb has launched its Responsible Space campaign, in which it has made the following commitments.<sup>1</sup>

1. **Employ Responsible Design and Operational Practices:** OneWeb has incorporated a safety-by-design approach into its space architecture and operations, from deployment and mission operations through disposal.
2. **Develop the Space Ecosystem:** OneWeb is supporting the development of new space technologies, particularly those that contribute to the preservation of the orbital environment.
3. **Support Positive Policy Outcomes through Collaboration:** OneWeb is a leading voice in promoting industry best practices and the adoption of sensible, internationally-coordinated requirements in national regulatory frameworks.

Regarding this second commitment, OneWeb believes it is critical that the global space community develop practical possibilities for environmental remediation. There is ongoing debate over how much debris we can leave in orbit before we tip into the realm of environmental instability, which objects would be most beneficial to remove, and how the costs of doing so should be covered. Nevertheless, it has become clearly evident that Active Debris Removal (ADR) will have to be an essential component of any comprehensive space environment management strategy. Atmospheric drag is the only natural sink (the effectiveness of which decreases exponentially with altitude), and the sources of debris are simply outpacing this cleansing process.

### 2.2 The Principal Challenges for ADR

There are several technical challenges associated with Active Debris Removal (ADR), but none are insurmountable. Industry has already demonstrated its ability to build and launch spacecraft capable of rendezvous, proximity operations, and even docking. Capturing a non-cooperative, potentially tumbling object, however, and then manipulating and maneuvering it for disposal are challenges still being worked on. A number of concepts have been proposed, and a few in-orbit demonstration missions have been conducted<sup>2</sup>, with more to come, to advance the Technology Readiness Levels (TRLs) of the most promising techniques.

However, perhaps the most formidable challenge facing the emergence of an ADR service industry is economic viability. To be commercially feasible, an ADR service has to represent a positive value proposition for its customers, and it is not yet clear what ADR services will cost, nor even who the principal customers will be. It remains to be seen whether ADR mission architectures and business models can be crafted to support price points that are attractive to commercial operators, or whether ADR is destined to be a service only governments can afford.

One proposed class of commercial customers is large constellation operators. As the argument goes, satellites that fail at their operational altitudes will have to be removed to make room for replacements and eliminate the possibility of intra-constellation collisions. However, in OneWeb's case, the constellation has been designed to be quite tolerant of satellite failures, so while maintaining a clean operating environment is preferable, this motivation

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<sup>1</sup> More information on OneWeb's Responsible Space campaign can be found at [www.responsible.space](http://www.responsible.space)

<sup>2</sup> Examples include the RemoveDebris and the Orbital Express missions.

does not support a high valuation for ADR services. Likewise, having an ADR option available may provide benefits for an operator seeking regulatory approval, or soliciting investors, or seeking a means to fulfill its commitments to environmental stewardship in the aftermath of unexpected satellite failures, but these too are all soft market drivers. These benefits are all real, but even when taken in aggregate, ADR services will have to be offered at extremely low cost if there is to be any significant market penetration with commercial operators.

### 2.3 Some Promising Opportunities

As part of our commitment to space sustainability and environmental stewardship, OneWeb is working with governments and industry on creative ADR mission concepts with an aim to minimize the deorbit cost per satellite. It is clear, for example, that service providers will need to be able to retrieve multiple objects – and perhaps many – on a single ADR mission for the per-satellite removal cost to be attractive to commercial operators. Also being discussed are some equally creative proposals for how ADR services might be packaged, from pay-per-mission service and orbit maintenance options, to ones that involve insurance coverage.

Another way to significantly reduce cost is to minimize the extent to which an ADR mission must be tailored in servicing one customer vs. another. Different satellites are different sizes and shapes, have different mass properties, and operate in different orbits, so any opportunity for technology reuse, component modularity, or interface standardization will dramatically reduce the cost and complexity of addressing a diverse marketplace.

It is in the spirit of this last point that OneWeb has committed to including a grappling fixture on every one of its satellites, facilitating capture in the event a retrieval should become necessary. Furthermore, over the last three years, OneWeb has worked with Altius Space Machines on advanced grappling techniques in the hopes of standardizing a versatile capture interface for on-orbit servicing, thereby lowering the projected cost of ADR and other services for everyone. The result is the DogTag™ universal grappling fixture, developed by Altius.

## 3 THE DOGTAG™ UNIVERSAL GRAPPLING FIXTURE

Altius Space Machines is introducing its DogTag™ universal grappling fixture, which provides a lightweight, inexpensive, and reliable method for a client satellite to be captured by a servicing vehicle. DogTags™ are designed to enable a very wide range of grappling methods, enabling low-cost satellite servicing and backup end-of-life disposal services (Fig. 4).

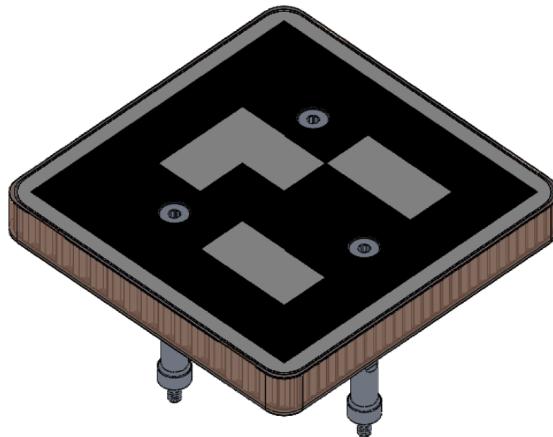


Fig. 4: Flight design of the DogTag™ universal grappling fixture

### 3.1 DogTag™ Design Genesis

Starting in 2011, Altius began experimenting with various gripping technologies for grappling satellites and other space objects. Early-on in this process, Altius realized that one of the best technologies for grappling an uncontrolled space object is via magnetic attraction, owing to a magnet's ability to exert useful attractive forces over modest distances, the gripping strength of magnets, and the ease with which a magnet's grip can be released. A magnetically quiet environment is often required within a satellite, however, so ferrous materials are typically

avoided in designing and constructing spacecraft. Therefore, a ferrous grappling fixture would need to be added to a satellite prior to launch for this technique to be useful.

In 2016, Altius began working with OneWeb to create a ferrous grappling fixture that could be integrated on OneWeb's LEO constellation satellites and would be magnetically neutral to the function of the spacecraft. Furthermore, if this fixture also included optical fiducial markings on its outward-facing surface, those fiducials would make relative navigation between the servicing and client vehicles easier and safer.

While featuring the magnetic capabilities as its primary capture mechanism, the companies set out to design the fixture to be able to accommodate as many other capture techniques as possible, with the goal of creating a standard interface that could be used on a wide variety of satellites and in support of a range of on-orbit services. To accomplish this, the ferrous gripping target was integrated into a honeycomb panel and mounted on standoffs to allow it to be used with mechanical grippers, adhesives, and harpoons, in addition to magnets. More specifically, the DogTag™ supports gripping via magnetic attraction; electrostatic, gecko, hot-melt, or chemical adhesives; mechanical pinch grasping or snare capture; and even harpooning. DogTags™ are also very simple to integrate onto a spacecraft, requiring only 3x M5 threaded inserts to be installed on the host and Allen key torque drivers for installation.

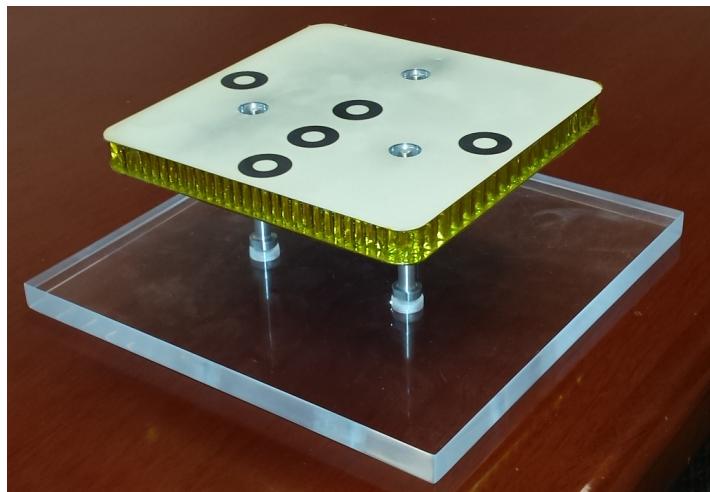


Fig. 5: DogTag™ Proof-of-Concept Prototype

Initial development for the DogTag™ was internally funded by Altius, with support from RUAG Space US on the design and manufacturing of the composite metal honeycomb panels, from Astroscale on the design and testing of the relative navigation optical fiducials, and from OneWeb and OneWeb Satellites on design requirements and spacecraft compatibility compliance. A Proof-of-concept prototype is shown in Fig. 5.

In 2019, after several years of internal development, Altius was awarded a contract from OneWeb Satellites to finalize and flight-qualify the DogTag™, and to produce and deliver almost 600 DogTags™ for integration into OneWeb's initial satellite fleet. The first flight-qualified DogTag™ grapple fixtures will be delivered in December 2019 to OneWeb Satellites for integration at their high-volume satellite production facility in Florida.

### 3.2 DogTag™ Design and Use Cases

Adoption of this fixture by OneWeb enables the DogTag™ to be the first high-production satellite grappling fixture and the authors propose that industry consider adopting it as a standard grappling interface for small satellites. The DogTag™ grappling fixture consists of a composite metal honeycomb gripping panel with three captive fasteners, and three 50 mm aluminum standoffs that mount it to the client spacecraft. Figure 6 illustrates the components of the DogTag™ which are described below, and its key features are summarized at the end of this section in Table 1.

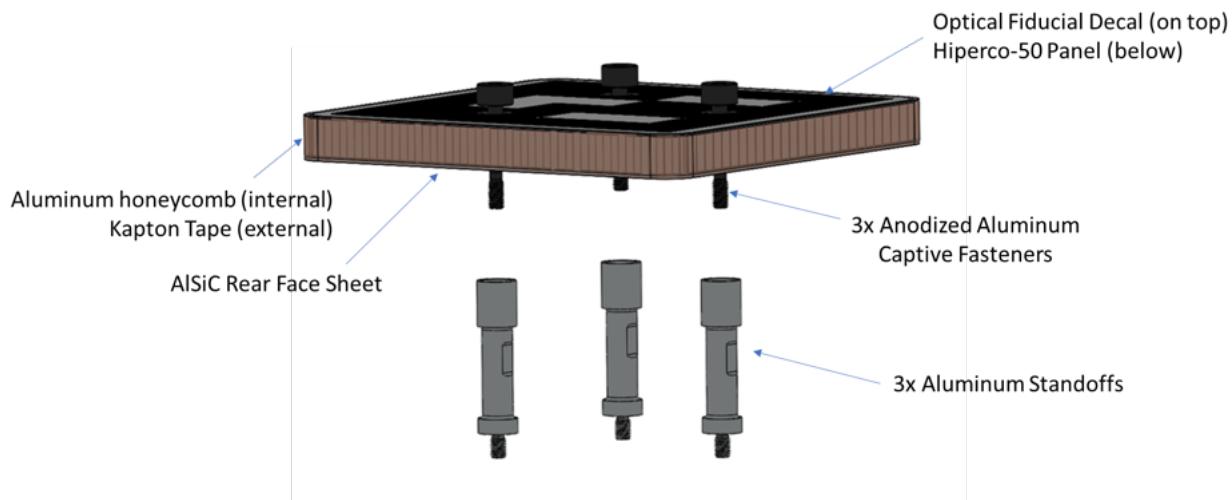


Fig. 6: DogTag™ Components

- **Optical Fiducial Decal:** The outermost surface of the composite panel is a thin (0.127mm) aluminum decal that has an optical fiducial pattern impregnated into its outer face using a MetalPhoto™ process. This enables a servicing vehicle to estimate its relative pose and range to the DogTag™ using IR or Visual cameras and machine vision algorithms. The decal is adhesively bonded onto the composite panel's front facesheet in a way that ensures electrical bonding between the decal and the rest of the composite panel.
- **Hiperco Front Facesheet:** The next layer of the composite panel is a facesheet made of Hiperco-50, a magnetically soft Fe-Co alloy with high saturation magnetization ( $B_s = 2.4\text{T}$ ), and a very low magnetic coercivity ( $H_c = 32 \text{ A/m}$ ). The high saturation flux enables strong magnetic gripping, while the low coercivity minimizes the facesheet's worst-case residual magnetic dipole. The Hiperco-50 is plated and treated to protect it from corrosion during handling and launch, and to maximize bond strength to the aluminum honeycomb.
- **Aluminum Honeycomb:** The core of the composite panel is an aluminum honeycomb, of similar design to that used in many other spacecraft composite honeycomb panels. The aluminum honeycomb provides stiffness to the composite panel and ensures good electrical conductivity. The panel has some counterbored inserts embedded into it during production for the mounting fasteners to mate against.
- **AlSiC Rear Facesheet:** The rear facesheet of the honeycomb panel is made of a special Aluminum-Silicon Carbide metal matrix composite (AlSiC). By tailoring the fill fraction of the Silicon Carbide particles, the CTE of the rear facesheet can be matched to the Hiperco, minimizing thermal distortions of the DogTag™ on-orbit.
- **Kapton Tape:** The outer edges of the composite panel are wrapped in a single layer of Kapton tape, as is traditional for spacecraft metal honeycomb panels.
- **Captive Fasteners:** The composite panel has three black-anodized aluminum, captured fasteners attached to it prior to delivery. These fasteners not only mount the panel to the standoffs, but were designed to minimize optical variations at different visual angles to simplify machine vision recognition of the DogTag™ optical fiducials. The DogTag™ captured fasteners and standoffs are designed so they can be secured to the spacecraft using Allen key torque drivers from the outward-facing side of the DogTag™. Using captured fasteners means that the DogTag™ can be shipped in only four pieces.
- **Aluminum Standoffs:** The composite panel is mounted to the spacecraft via three aluminum standoffs. These standoffs feature a male M5x0.8 thread on the spacecraft side, and an internal Allen-key drive and female M5x0.8 thread on the DogTag™ side, into which the captive fasteners thread.

Table 1: DogTag™ Key Features

Bounding Volume	150mm x150mm x 65mm
Total Mass	250g
Mounting Interface	3x M5x0.8 threaded inserts on an 84.5mm bolt-hole circle
Compatible Gripping Methods	Magnetic Capture Adhesive Capture - Electrostatic - Gecko - Hot-Melt - Chemical Mechanical Capture - Pinch-Grasp - Snare Penetrating Capture (Harpoon)

#### 4 CONCLUSION

If we are to avoid a tragedy of the commons in space, stakeholders must work together on a comprehensive approach to preserving the space environment as a natural resource. As part of this quest, OneWeb urges all stakeholders to look beyond their own mission assurance goals and join us in supporting the development of environment remediation technologies and the nascent ADR services industry.

For ADR to become an economically viable commercial service offering, the cost per removal must be high enough to derive a profit while being low enough to attract a non-governmental customer base. To do this, industry must be creative with mission profiles that can deorbit multiple objects with a single mission. Anything industry can do to standardize hardware interfaces, and design modular solutions that can serve a wide variety of use cases, will also go a long way toward reducing the cost of ADR and other on-orbit servicing missions.

OneWeb and Altius are working together, and with governments and other industry partners, to simplify small-satellite rendezvous and capture. As one very tangible milestone, Altius has designed a versatile, low-cost, low-mass grappling fixture to facilitate on-orbit capture of a non-cooperative satellite. OneWeb is integrating Altius' DogTag™ fixture on its satellites and would like to invite other stakeholders to help make the DogTag™ an industry standard interface.

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